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(54) **GAMMA RAY MEASUREMENT APPARATUS, SYSTEMS, AND METHODS**

(71) Applicant: **Halliburton Energy Services, Inc.**, Houston, TX (US)

(72) Inventors: **Da Luo**, Houston, TX (US); **Weijun Guo**, Houston, TX (US)

(73) Assignee: **HALLIBURTON ENERGY SERVICES, INC.**, Houston, TX (US)

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G01T 1/40 (2006.01)
E21B 49/00 (2006.01)
G01T 1/20 (2006.01)

(52) **U.S. Cl.**
CPC ***G01V 5/06*** (2013.01); ***E21B 49/00*** (2013.01); ***G01T 1/40*** (2013.01); *G01T 1/2018* (2013.01)

(58) **Field of Classification Search**
CPC G01V 5/06; G01V 5/101; E21B 49/00
See application file for complete search history.

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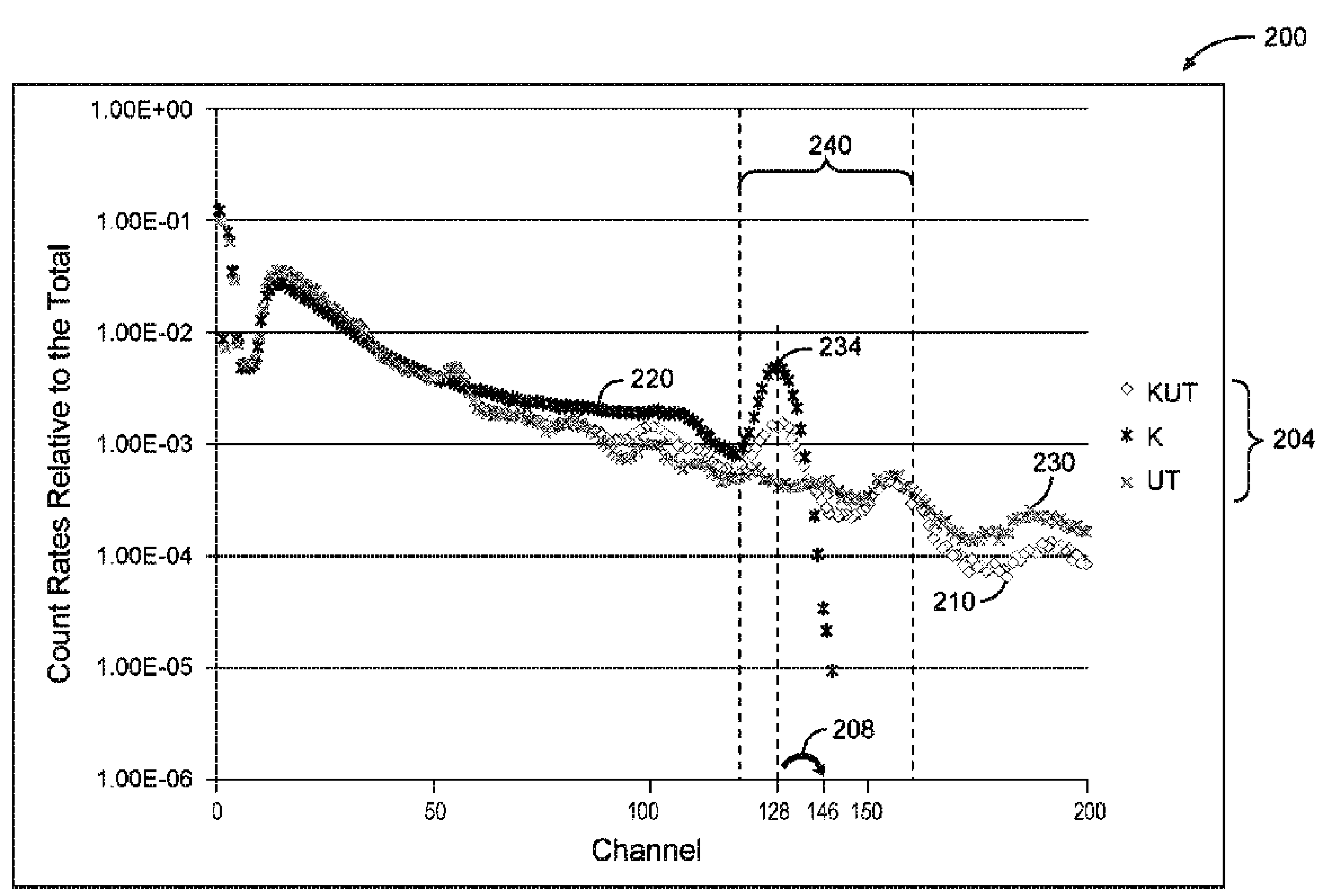
Primary Examiner — Marcus Taningco
(74) *Attorney, Agent, or Firm* — Haynes and Boone, LLP

(57) **ABSTRACT**

In some embodiments, an apparatus and a system, as well as a method and article, may operate to detect gamma radiation as detected gamma radiation, and to determine a relative level of potassium decay energy within a selected band of energy levels, with respect to a combination of at least two of potassium, uranium, or thorium. Further operations may include adjusting at least one of a detector supply voltage or an analyzer gain to place the potassium decay energy at a selected energy level location when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels. Additional apparatus, systems, and methods are disclosed.

20 Claims, 6 Drawing Sheets



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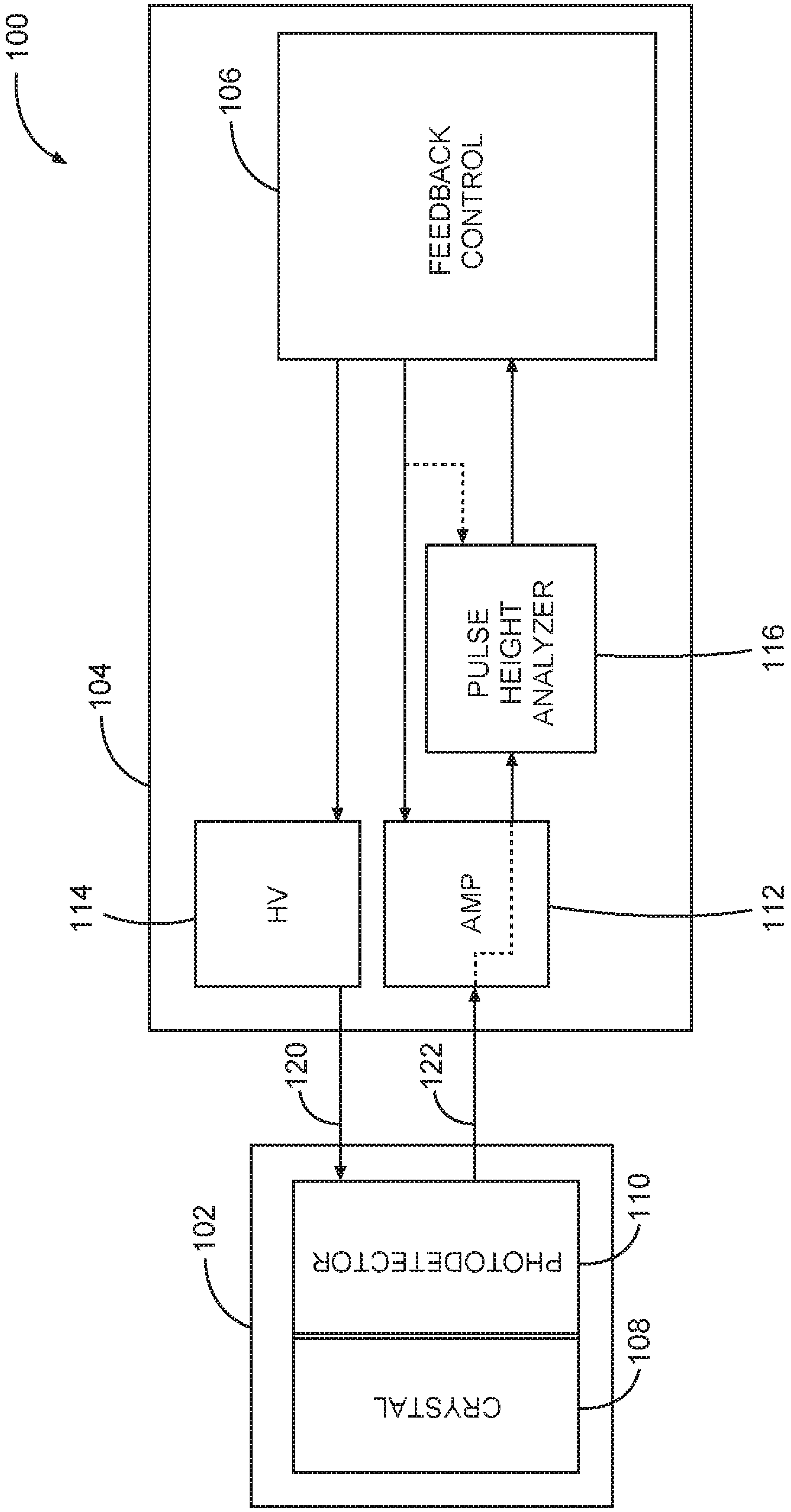
100
106
FEEDBACK CONTROL
104
PULSE HEIGHT ANALYZER
116
114
HV
AMP
112
120
122
102
PHOTODETECTOR
110
CRYSTAL
108

Fig. 1

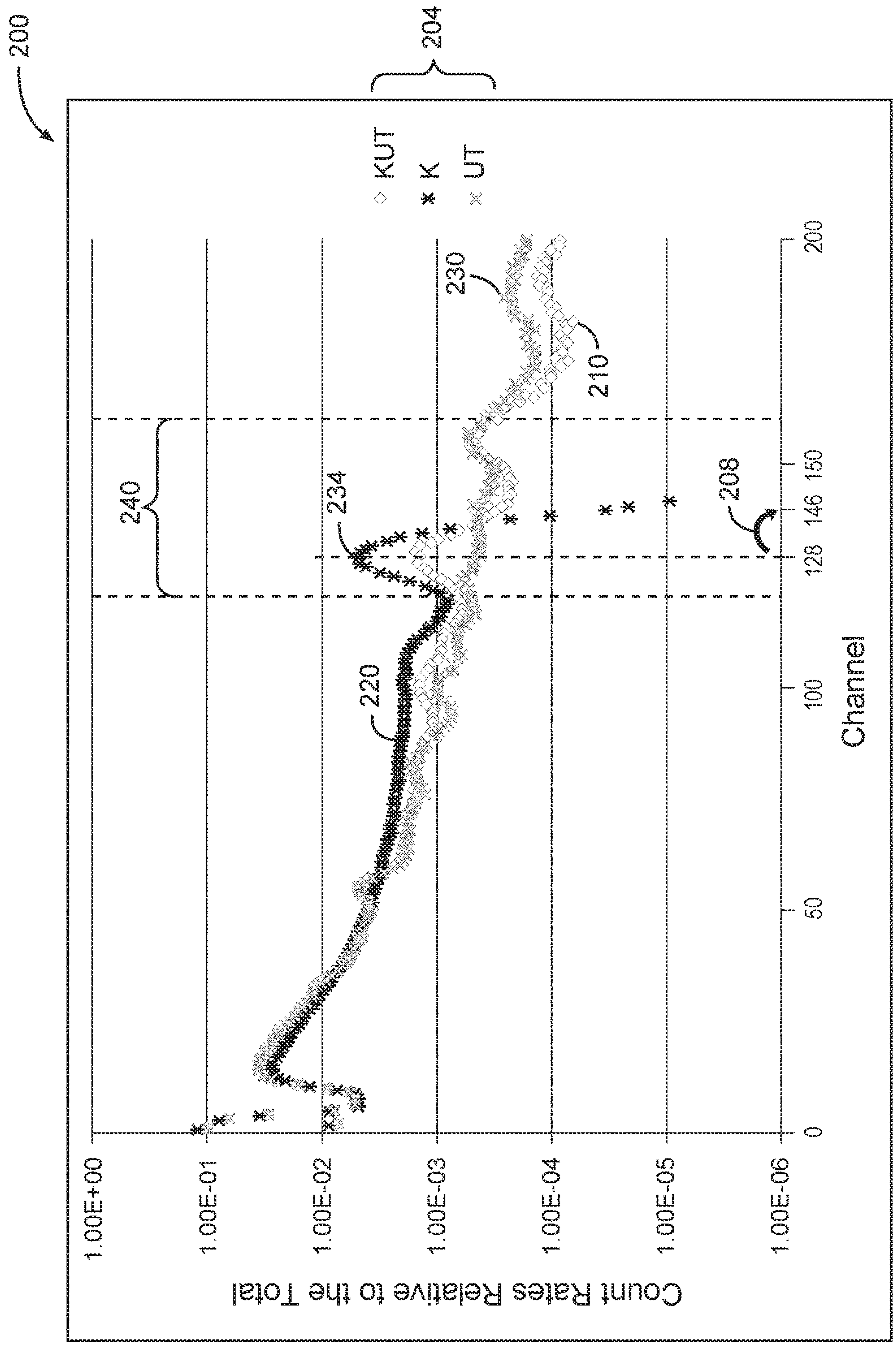
200
204
KUT
K
UT
230
210
240
234
220
208
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
Count Rates Relative to the Total
0
50
100
128
146
150
200
Channel

Fig. 2

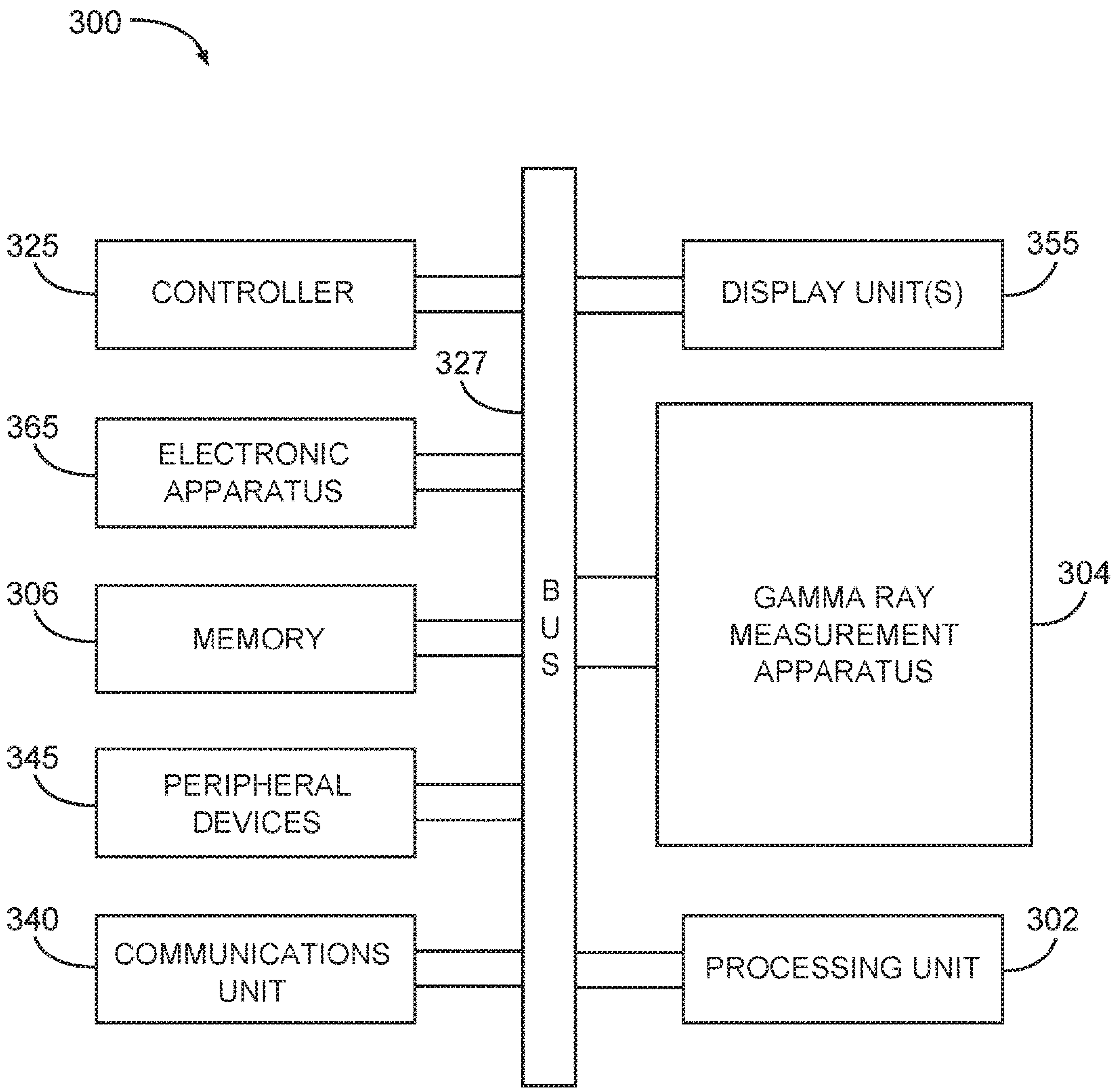
300
325
CONTROLLER
327
365
ELECTRONIC APPARATUS
306
MEMORY
345
PERIPHERAL DEVICES
340
COMMUNICATIONS UNIT
B U S
355
DISPLAY UNIT(S)
304
GAMMA RAY MEASUREMENT APPARATUS
302
PROCESSING UNIT

Fig. 3

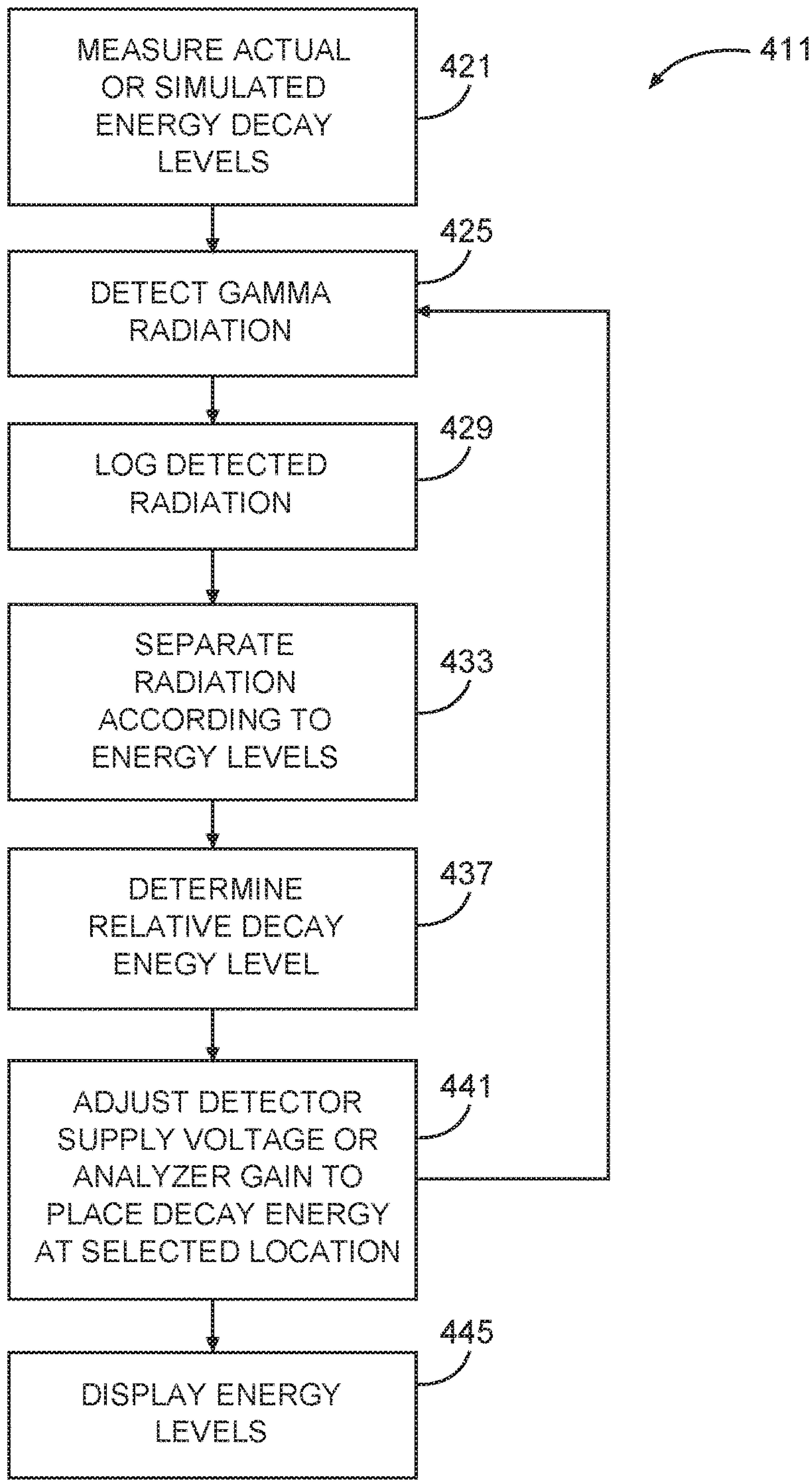
411
MEASURE ACTUAL OR SIMULATED ENERGY DECAY LEVELS
421
DETECT GAMMA RADIATION
425
LOG DETECTED RADIATION
429
SEPARATE RADIATION ACCORDING TO ENERGY LEVELS
433
DETERMINE RELATIVE DECAY ENEGY LEVEL
437
ADJUST DETECTOR SUPPLY VOLTAGE OR ANALYZER GAIN TO PLACE DECAY ENERGY AT SELECTED LOCATION
441
DISPLAY ENERGY LEVELS
445

Fig. 4

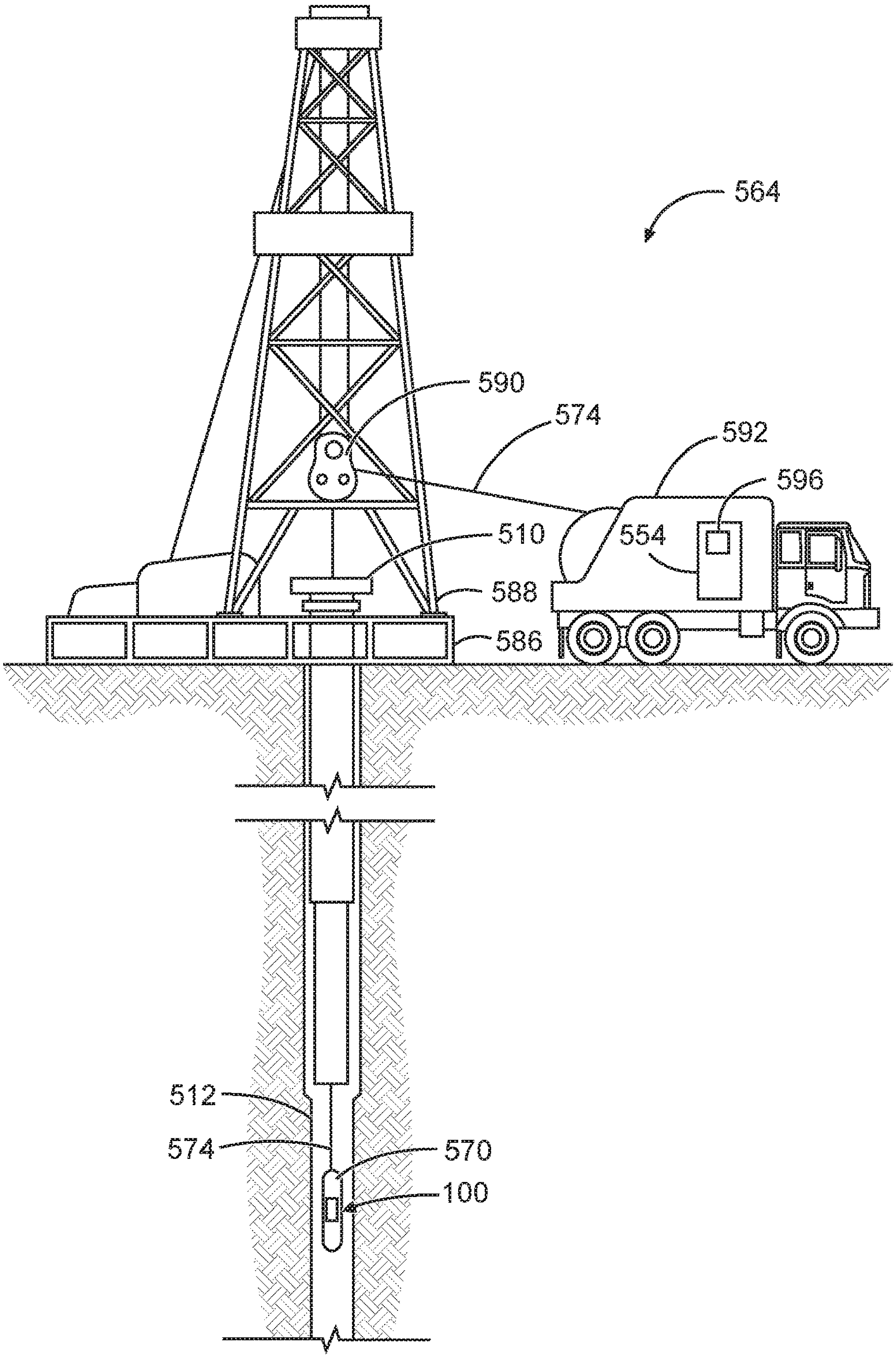

Fig. 5

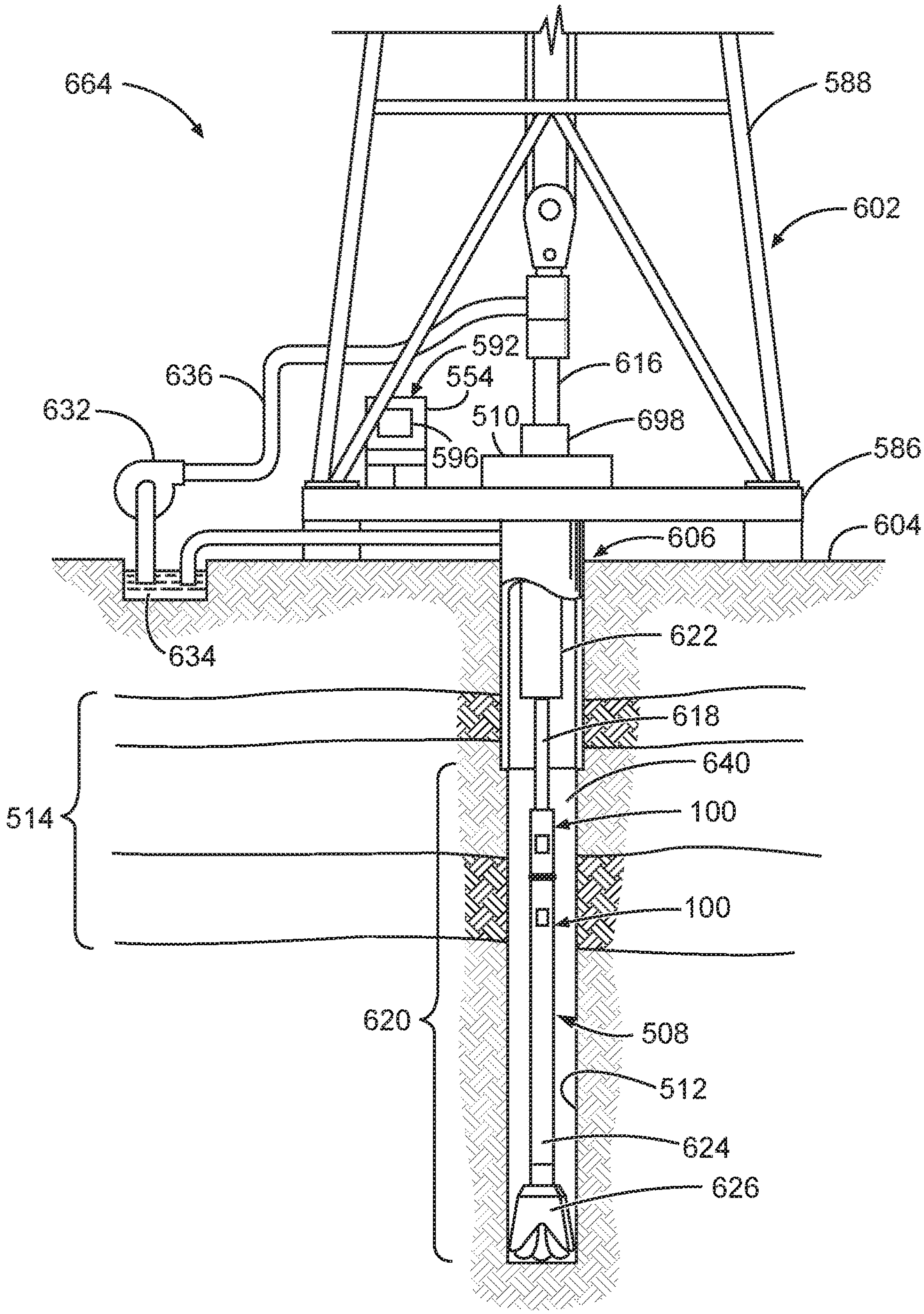
664
588
602
592
616
636
554
632
510
698
596
586
604
606
622
618
640
100
514
100
620
508
512
624
626

Fig. 6

GAMMA RAY MEASUREMENT APPARATUS, SYSTEMS, AND METHODS

PRIORITY APPLICATIONS

This application is a U.S. National Stage Filing under 35 U.S.C. 371 from International Application No. PCT/US2014/068570, filed on 4 Dec. 2014, which application is incorporated herein by reference in its entirety.

BACKGROUND

Understanding the structure and properties of geological formations can reduce the cost of drilling wells for oil and gas exploration. Measurements made in a borehole (i.e., downhole measurements) are typically performed to attain this understanding, to identify the composition and distribution of material that surrounds the measurement device downhole. To obtain such measurements, gamma ray detectors are often used to measure naturally-occurring gamma radiation downhole. However, the output of some gamma ray detectors may fluctuate due to environmental conditions downhole. These fluctuations can cause changes in the apparent energy level detected by the gamma ray detector, leading to inaccuracies in the measurements reported by the tool. Thus, compensation techniques have been developed.

One is to implant an artificial radioactive source in the detector and use its signature energy as a reference. Another is to compare the signals from two detectors. However the first suffers from transportation restrictions, and is also limited by the computing power available downhole, or the available telemetry bandwidth, due to extensive calculations that implement whole spectrum curve fitting. The second increases the expense of the tool.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a gamma ray measurement apparatus in accordance with various embodiments of the invention.

FIG. **2** depicts example gamma spectra in three different formation environments with channel shifting indicated in accordance with various embodiments of the invention.

FIG. **3** is a block diagram of a logging system according to various embodiments of the invention.

FIG. **4** is a flow diagram illustrating methods of stabilizing gamma ray measurement apparatus gain, according to various embodiments of the invention.

FIG. **5** depicts an example wireline system, according to various embodiments of the invention.

FIG. **6** depicts an example drilling rig system, according to various embodiments of the invention.

DETAILED DESCRIPTION

To address some of the challenges described above, as well as others, apparatus, systems, and methods are described herein for stabilizing the gain of gamma ray detectors. For example, a method is disclosed herein to stabilize the spectrum during natural gamma ray logging, when the potassium contribution to the spectrum is significant. The method provides a simplified and way to speed up the process of gain stabilization, without using an embedded radiation source in the tool, and without the extensive calculations that are associated with whole-spectrum curve fitting. In addition, better utilization of the pulse height analyzer energy scale can increase the precision of the spectrum results.

The details of various embodiments will now be described.

FIG. **1** is a block diagram of a gamma ray measurement apparatus **100** in accordance with various embodiments of the invention. The gamma ray measurement apparatus **100** includes a downhole gamma ray detector **102** and a signal processor **104**, which in turn may comprise a feedback control **106**. In some embodiments, the feedback control **106** is located outside of the signal processor **104**.

The gamma ray detector **102** detects the natural gamma radiation. The gamma ray detector **102** can include a Scinturion gamma module, available from General Electric of Fairfield, Conn., for example, or other gamma ray detectors utilizing sodium-iodine (NaI)-based scintillation crystals, although many embodiments are not limited thereto. Natural gamma radiation is the result of radiation by a variety of elements, including potassium, uranium, and thorium—which are often present in subterranean formation environments. One of more parts of the apparatus **100**, including the gamma ray detector **102**, may be attached to a drilling assembly for logging while drilling (LWD) or measuring while drilling (MWD) operations. Similarly, one or more parts of the apparatus may be attached to a wireline tool for logging an existing well. Such embodiments are described later herein with reference to FIGS. **5** and **6**. The gamma ray measurement apparatus **100** can include a plurality of gamma ray detectors, including a plurality of azimuthal gamma ray detectors.

Each gamma ray detector **102** operates to receive gamma ray energy emitted naturally by subsurface formations. Azimuthal gamma ray detectors may be located near the exterior of a logging tool and be spaced about a circumference of the tool. Thus, while a plurality of gamma ray detectors may be included in some of the apparatus **100** and systems described herein, only one is explicitly presented here for reasons of simplicity.

The gamma ray detector **102** provides signals that scale with the energy deposited by the gamma rays on the gamma ray detector **102**. The gamma ray detector **102** may include one or more scintillation crystals **108** to scintillate responsive to radiation emitted by a subterranean formation environment. The gamma ray detector **102** may also comprise an optically-coupled photodetector **110**, e.g., a photomultiplier tube, for transmitting light emitted by the scintillation crystals **108** within the detector **102**. In most embodiments, the gamma ray detector **102** does not include a reference scintillation crystal.

The gamma ray detector **102** is electrically coupled to a signal processor **104**. The signal processor **104** may include an amplifier **112**, a variable high voltage supply unit **114**, and pulse height analyzer **116**. As noted previously the feedback control **106** may also be included in the signal processor **102**.

The gamma ray detector receives a supply voltage from the high voltage supply unit **114**. One high voltage supply unit **114** may be used to power multiple gamma ray detectors. The high voltage supply unit **114** may be configured so that the output voltage **120** (which serves as the supply voltage for the detector **102**) can be adjusted by a feedback control **106**.

For the purposes of this document, “high voltage” means a voltage that is greater than 300 V, whether alternating or direct current. The high voltage supply unit **114** may thus be capable of providing an output voltage in a range of about

500-5000 volts. The high voltage supply unit **114** can include an ORTEC® Model 456 or Model 556 high voltage power supply, available from AMETEK, Inc. of Berwyn, Pa., although embodiments are not limited thereto.

The signal processor **104** includes one or more amplifiers **112** to modify (e.g., amplify) the amplitude of signals **122**, including electrical impulses provided by an output of the photodetector **110**. The gain of the amplifier **112** can be adjusted by the feedback control **106**. The signal processor **104** further includes the pulse height analyzer **116** to receive signals amplified by the amplifier **112** and representative of gamma ray measurements from the gamma ray detector **102**. The pulse height analyzer **116** can generate one or more spectra based on the received gamma ray measurements, and the pulse height analyzer **116** can provide this multi-channel spectrum to the feedback control **106**.

In some embodiments, the gain of the pulse height analyzer **116** is adjusted directly by the feedback control **106**, when no amplifier **112** is present in the signal processor **104**. The signal path in this instance is represented by the dashed lines that pass through the amplifier **112**, and that come from the feedback control **106** to the pulse height analyzer **116**. This arrangement may be used when the pulse height analyzer **116** has its own internal amplifier and/or gain adjustment.

The pulse height analyzer **116** may comprise circuitry similar to an ORTEC® EASY-NIM 928 combination MCB/quad counter/dual timer module, available from AMETEK, Inc, of Berwyn, Pa., although embodiments are not limited thereto. The gain stabilization device **106** controls the output voltage of the high voltage supply unit **114** and/or the gain of the pulse height analyzer **116** (either indirectly, via the output of the amplifier **112**, or directly, as shown via the dashed lines in the figure) to effectively adjust the gain of the gamma ray detector **102**.

In various embodiments, whether employed on a wireline (FIG. **6**) or as part of logging while drilling operations (FIG. **7**), the feedback control **106** receives the multi-channel spectrum from the pulse height analyzer **116** and records the spectrum across n channels (where n equals the number of channels). Each channel represents a range of energy levels, wherein the energy levels can be measured in units, such as kilo-electron volts (keV). The number of channels n may vary for different applications; for example, n may be 10, 16, 20, 50, 64, 100, 128, 150, 200, 256, 400 or more, or any number in between. In some embodiments, the range of channel numbers corresponds to energy values of 0 keV to 2000 keV, although embodiments are not limited thereto. The range of individual channel numbers may be set based on criteria such as electrical parameters of the gamma ray detector **102**. The pulse height analyzer determine the number of "counts" over its range of channels, where the count for a particular channel refers to the number of times gamma ray energy with the corresponding energy level is detected by the gamma ray detector **102**.

The gamma ray measurement apparatus **100** can be a gross counting gamma ray detector, wherein the process of determining the gross count involves developing counts over a plurality of channels arranged in a spectrum. The gain of the gamma ray detector **102** varies at times with certain variables, e.g., temperature, equipment limitations, high voltage of the photodetector **110** in the gamma ray detector **102**, etc. These variations will affect the counts stored in the various channels, leading to inaccurate measurement reports being reported by the gamma ray measurement apparatus **100**. To obtain a gross count that is not affected by these variations, the feedback control **106** stabilizes the gain of the gamma ray detector **102** by determining the channel number for the pulse height analyzer **116** that is associated with counts for Potassium, and then adjusting the output of the high voltage supply unit **114** and/or the gain of the pulse height analyzer **116**, to shift the location of the counts associated with Potassium from the channel number indicated by the analyzer **116**, to a desired location/channel number.

FIG. **2** depicts example gamma spectra **200** in three different formation environments **204** with channel shifting **208** indicated in accordance with various embodiments of the invention. The spectrum **220** is an example spectrum for a formation environment consisting essentially of potassium. As will be understood by those of ordinary skill in the art, this type of formation environment is useful as a reference, but may not occur commonly in the field. However most, if not all, formation environments will include at least some potassium due to the presence of high-potassium drilling fluids that have been placed downhole in drilling and exploration operations.

A potassium spectrum such as spectrum **220** may be generated as a reference prior to operation in the field, which allows representative count values to be known beforehand (e.g., using samples taken from downhole), to act as a limiting spectrum beyond which naturally occurring gamma radiation will typically not be observed.

The spectra **200** are examples of what can be generated by a pulse height analyzer based on values provided by a gamma ray detector in accordance with some embodiments. In FIG. **2**, each channel in the x-axis represents a unit measurement of energy, for example 12 keV, and the count rates (relative to the total spectrum) are measured for each channel are plotted on the y-axis.

In some embodiments, the feedback control **106** will operate within a range **240** of channels. This range **240** can be established using reference measurements, as noted previously, to span whatever range of drift is expected in the measurement of Potassium radiation.

To obtain the spectra **200**, a gamma detector which detects natural gamma ray radiation was used. The detector included a scintillation crystal type device, integrated with a photomultiplier. The detector was exposed to a variety of radiation, such as a combination **210** of Potassium, Uranium, and Thorium (KUT); Potassium **220** (K); and a combination **230** of Uranium and Thorium (UT).

A pulse height analyzer was used to receive signals from the detector. The analyzer provided, as output, a multichannel spectrum according to the pulse height of the received signals. In this case, the spectra for KUT, K, and UT are shown.

During operation of the apparatus **100**, an initial comparison of the count rates for each channel relative to the total count rates of the full spectrum is made. For a 200-channel system as shown in the figure, the counts of individual channels within a range of channels **240** are compared with the sum of counts for the total spectrum, since the energy level associated with Potassium decay (i.e., 1460 keV) drifts over some span that falls within the range **240** of channels. In this case, the range of energies monitored by channels **120** to **160** is expected to cover the maximum amount of drift that will be experienced during operations downhole. Then, if the count rates of one or more channels within the range **240** are larger than 1/1000 of the total count rates, it can be assumed that the spectrum as a whole is strongly affected by Potassium radiation.

As will be explained shortly, once the potassium contribution is confirmed, a specific channel (here, channel **128**) within the range **240** of channel numbers **120** to **160** that has a maximum count rate **234** is chosen to be associated with the potassium decay energy (i.e., 1460 kev).

At this point, the high voltage power supply unit output and/or the pulse height analyzer gain can be adjusted to shift the energy monitored by channel **128** to any desired channel. If this process of measurement, comparison, and adjustment occur on a periodic basis, so that the detected Potassium radiation count is consistently shifted to a fixed channel number (e.g., channel **146**, corresponding to 1460 keV in this case) the spectrum gain for the detector will be relatively stable.

If it turns out that the Potassium contribution to the spectrum **220** is not significant (e.g., there is no peak for detected Potassium radiation within the range **240**), then other methods can be used to stabilize the gain. Thus, many embodiments may be realized.

For example, referring now to FIGS. **1-2**, in some embodiments, an apparatus **100** may comprise a gamma radiation detector **102**, a pulse height analyzer **116**, and feedback control **106**. Feedback from the pulse height analyzer **116** may be used to adjust the input voltage level of the radiation detector **102**, and/or the gain of the pulse height analyzer **116**. As noted previously, gamma radiation detectors including NaI and other scintillation crystals are available from the General Electric Company of Fairfield, Conn.

In some embodiments, an apparatus **100** comprises a gamma radiation detector **102** to receive a detector supply voltage, the gamma radiation detector **102** being used to detect gamma radiation. The apparatus **100** may also include a pulse height analyzer **116** coupled to the gamma radiation detector **102**, the pulse height analyzer **116** being used to determine a relative level of potassium decay energy within a selected band of energy levels (e.g., the range **240**), with respect to a combination of at least two of potassium, uranium, or thorium (e.g., KUT, or UT, etc.).

The apparatus **100** may further include a feedback control **106** to adjust at least one of the detector supply voltage (e.g., the output voltage of the supply **114**) or the analyzer gain of the pulse height analyzer **116** to place the potassium decay energy at a selected energy level location (e.g., channel **146** as shown in FIG. **2**) when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels.

For example, in some embodiments, including those that make use of the detectors, power supply, and pulse height analyzer described above, the potassium contribution may be confirmed using a predetermined threshold that is 1/1000 of the total count. Confirmation of the potassium contribution can be accomplished by first calculating the total count rate—over all channels (e.g., **200** in the given example). Second, a ratio of count rates is calculated for each individual channel. This is done by selecting a one channel at a time, and dividing its individual count rate by the previously-calculated total count rate. This "ratio of count rates" is determined for each channel in the range **240**. If there is at least one channel having a ratio of count rates that turns out to be larger than 1/1000, then the potassium contribution in the spectrum is confirmed.

Thus, in this particular case, the value of 1/1000 is set as a threshold value for the ratio of count rates. This value serves as the threshold for a particular detector and electronics combination (e.g., a General Electric NaI scintillator or Hamamatsu ruggedized high temperature PMT, in combination with the high voltage supply and pulse height analyzer electronics described previously). If the crystal material in the detector is changed, or the sensitivity of other electronics in the chain are changed, the value of 1/1000 may also change, as is well known to those of ordinary skill in the art.

For example, this threshold value might increase to 1/500 when the detector-system response for the 1.4 keV energy gamma of potassium relative to the total gamma energy spectrum range is twice as sensitive as the detector-system that incorporates the components named above. This threshold value might decrease to 1/2000 when the detector-system response for the 1.4 keV energy gamma of potassium relative to the total gamma energy spectrum range is half as sensitive as the detector-system that incorporates the components named above. In other words, the response of the detector and its processing electronics to the 1.4 keV energy gamma of potassium determines the actual value that is useful for a threshold value in many embodiments. The response to a selected energy level (e.g., 1.4 keV in this case) relative to the total gamma energy spectrum range is the strength of the signal generated by the system at the selected energy, relative to the total strength of signals generated across the full energy spectrum.

In some embodiments, the apparatus **100** may include a high voltage power supply **114** to supply the detector supply voltage.

The gain analyzer may operate to divide the energy spectrum into a number of bins, or channels. Thus, the analyzer gain may be associated with a pulse height analyzer **116** having an energy analysis spectrum comprising a number of channels into which energy is approximately equally divided (e.g., for a total spectrum that spans 2000 keV, each one of 200 channels may be allocated a span of 10 keV).

The selected band of energy levels may correspond to a set of channels on the pulse height analyzer **116**. The location selected for the potassium decay energy (i.e., the channel location to which the potassium energy decay count is shifted) may lie within a selected band of channels on the pulse height analyzer **116**. Thus, the selected energy level location may correspond to a single channel on the pulse height analyzer, where the single channel is included in the set of channels on the analyzer **116** (e.g., as shown in FIG. **2**, the selected energy level location of channel **146** is included in the channel range **240**. Still further embodiments may be realized.

For example, FIG. **3** is a block diagram of a logging system **300** according to various embodiments of the invention. Referring now to FIGS. **1** and **3**, it can be seen that the logging system **300** can receive count measurements or other data from the gamma ray measurement apparatus **100** and provide gain stabilization for one or more gamma ray detectors **102** of the gamma ray measurement apparatus **100**. The logging system **300** includes gamma ray measurement apparatus **304** operable in a wellbore. The gamma ray measurement apparatus **304** may be similar to or identical to the apparatus **100**.

The processing unit **302** can perform functions that are executed by the feedback control **106** in addition to other control functions. The processing unit **302** can couple to the gamma ray measurement apparatus **304** to obtain measurements from the gamma ray measurement apparatus **304** as described earlier herein. In some embodiments, a logging system **300** comprises one or more of the gamma ray measurement apparatus **304**, as well as a housing (not shown in FIG. **3**; see FIGS. **5-6**) that can house the gamma ray measurement apparatus **304** or other electronics. The housing might take the form of a wireline tool body, or a downhole tool as described in more detail below with reference to FIGS. **5** and **6**. The processing unit **302** may be part of a surface workstation or attached to a downhole tool housing. In some embodiments, the processing unit **302** is packaged within the gamma ray measurement apparatus **304**, as described earlier herein.

The logging system **300** can include a controller **325**, other electronic apparatus **365**, and a communications unit **340**. The controller **325** and the processing unit **302** can be fabricated to operate the gamma ray measurement apparatus **304** to acquire measurement data, such as radiation energy counts.

Electronic apparatus **365** (e.g., electromagnetic sensors, etc.) can be used in conjunction with the controller **325** to perform tasks associated with taking measurements downhole with the gamma ray measurement apparatus **304**. The communications unit **340** can include downhole communications in a drilling operation. Such downhole communications can include a telemetry system.

The logging system **300** can also include a bus **327** to provide common electrical signal paths between the components of the logging system **300**. The bus **327** can include an address bus, a data bus, and a control bus, each independently configured. The bus **327** can also use common conductive lines for providing one or more of address, data, or control, the use of which can be regulated by the controller **325**.

The bus **327** can include instrumentality for a communication network. The bus **327** can be configured such that the components of the logging system **300** are distributed. Such distribution can be arranged between downhole components such as the gamma ray measurement apparatus **304** and components that can be disposed on the surface of a well. Alternatively, several of these components can be co-located such as on one or more collars of a drill string or on a wireline structure.

In various embodiments, the logging system **300** includes peripheral devices that can include displays **355**, additional storage memory, or other control devices that may operate in conjunction with the controller **325** or the processing unit **302**. The display **355** can display diagnostic information for the gamma ray measurement apparatus **304** based on the signals generated according to embodiments described above. The display **355** can also be used to display one or more spectra **200**, similar to what is illustrated in FIG. **2**.

In an embodiment, the controller **325** can be fabricated to include one or more processors. The display **355** can be fabricated or programmed to operate with instructions stored in the processing unit **302** (for example in the memory **306**) to implement a user interface to manage the operation of the gamma ray measurement apparatus **304** or components distributed within the logging system **300**. This type of user interface can be operated in conjunction with the communications unit **340** and the bus **327**. Various components of the logging system **300** can be integrated with the gamma ray measurement apparatus **304** or associated housing such that processing identical to or similar to the methods discussed with respect to various embodiments herein can be performed downhole.

In various embodiments, a non-transitory machine-readable storage device can comprise instructions stored thereon, which, when performed by a machine, cause the machine to become a customized, particular machine that performs operations comprising one or more features similar to or identical to those described with respect to the methods and techniques described herein. A machine-readable storage device, herein, is a physical device that stores information (e.g., instructions, data), which when stored, alters the physical structure of the device. Examples of machine-readable storage devices can include, but are not limited to, memory **306** in the form of read only memory (ROM), random access memory (RAM), a magnetic disk storage device, an optical storage device, a flash memory, and other electronic, magnetic, or optical memory devices, including combinations thereof.

The physical structure of stored instructions may be operated on by one or more processors such as, for example, the processing unit **302**. Operating on these physical structures can cause the machine to perform operations according to methods described herein. The instructions can include instructions to cause the processing unit **302** to store associated data or other data in the memory **306**. The memory **306** can store the results of measurements of formation parameters or parameters of the gamma ray measurement apparatus **100**, to include gain parameters, calibration constants, identification data, etc. The memory **306** can store a log of the gamma radiation detected by the gamma ray detector **102**. The memory **306** therefore may include a database, for example a relational database.

FIG. **4** is a flow diagram illustrating methods **411** of stabilizing gamma ray measurement apparatus gain, according to various embodiments of the invention. The methods **411** described herein are with reference to hardware circuitry, spectra, channel ranges, channel shifting, etc. shown in FIGS. **1-3**. Some operations of the methods **411** can be performed in whole or in part by the feedback control **106** (FIG. **1**), or any component of system **300** (FIG. **3**) or gamma ray measurement apparatus **100** (FIG. **1**), although many embodiments are not limited thereto.

In some embodiments, a method **411** comprises detecting gamma radiation at block **425**, determining the relative level of potassium decay energy at block **437**, and then, at block **441**, adjusting the detector supply voltage and/or analyzer gain to locate the potassium decay energy at a specific place in the detected energy spectrum. Many variations may be realized.

For example, in some embodiments, simulation results can be used to determine the relative level of potassium decay energy. Thus, a method **411** may begin at block **421** with measuring actual or simulated energy decay levels of a combination of at least two of potassium, uranium, or thorium (e.g., UT, KUT, etc.), to determine the relative level of potassium (K) decay energy.

The method **411** may go on to block **425** to include detecting gamma radiation as detected gamma radiation.

In most embodiments, a single detector is used for stabilization and logging. Thus, the method **411** may include, at block **429**, logging the detected gamma radiation as part of a downhole logging operation.

The detected gamma radiation can be separated, or binned, into a variety of energy levels. Thus, the method **411** may comprise separating the detected gamma radiation according to a preselected number of energy levels at block **433**.

The method **411** may go on to block **437** to include determining a relative level of potassium decay energy within a selected band of energy levels, with respect to a combination of at least two of potassium, uranium, or thorium.

The relative level of potassium decay energy can be determined by integrating energy level counts over multiple channels and making a comparison with the integrated counts. Thus, determining the relative level of potassium decay energy within the selected band of energy levels at block **437** may comprise comparing individual potassium decay energy level counts over a predetermined spectrum channel bandwidth to an integrated energy count over the predetermined spectrum channel bandwidth comprising multiple channels that occupy at least the selected band of energy levels.

At block **441**, the method **411** may include adjusting at least one of a detector supply voltage or an analyzer gain to place the potassium decay energy at a selected energy level location when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels.

The relative potassium decay energy can be displayed, along with energies associated with combinations of elements. Thus, the method **411** may include, at block **445**, displaying the relative level of potassium decay energy along with the combination of at least two of potassium, uranium, or thorium, in a visible format (e.g., in a manner similar or identical to what is shown in FIG. **2**).

The bandwidth associated with the selected band of energy levels can be selected to accommodate the expected location that will be selected as an adjustment—the location in the detection spectrum to which the measured level of potassium decay energy will be moved, to be used as a reference in the future. Thus, the selected band of energy levels may include a measured energy level of 1460 keV.

The selected band of energy levels can be selected to include a bandwidth that accommodates drift in the measured potassium energy decay level. Thus, the selected band of energy levels may have an energy level width sufficient to include an expected amount of energy level measurement drift with respect to the potassium decay energy.

The band of energy levels may form part of an evenly divided, channelized structure. Thus, the selected band of energy levels may form a portion of a set of numbered channels that approximately evenly divide a detected energy spectrum into a fixed number of bins.

The operation of a gamma radiation detection system can be stabilized in real-time, by repeatedly applying the actions of detecting, determining the relative potassium decay energy level, and adjusting the detector supply voltage and/or analyzer gain in response. Thus, the method **411** may comprise repeating the detecting (at block **425**), the determining (at block **437**), and the adjusting (at block **441**) on a periodic basis to provide operational stabilization of a gamma radiation detection system.

Simulation results can be used to stabilize the gamma radiation detection system. Thus, placing the potassium decay energy at a selected energy level location may comprise the activity of moving a measured or simulated peak potassium decay energy location associated with one of the bins to another one of the bins associated with the selected energy level location.

As described earlier herein, gamma ray measurement tools can be used in an LWD assembly or a wireline logging tool. FIG. **5** depicts an example wireline system, according to various embodiments of the invention. FIG. **6** depicts an example drilling rig system, according to various embodiments of the invention.

Either of the systems in FIG. **5** and FIG. **6** are operable to control a gamma ray measurement apparatus **100** to conduct measurements in a wellbore. Thus, the systems **564**, **664** may comprise portions of a wireline logging tool body **570** as part of a wireline logging operation, or of a downhole tool **624** (e.g., a drilling operations tool) as part of a downhole drilling operation.

Returning now to FIG. **5**, a well during wireline logging operations can be seen. In this case, a drilling platform **586** is equipped with a derrick **588** that supports a hoist **590**.

Drilling oil and gas wells is commonly carried out using a string of drill pipes connected together so as to form a drilling string that is lowered through a rotary table **510** into a wellbore or borehole **512**. Here it is assumed that the drilling string has been temporarily removed from the borehole **512** to allow a wireline logging tool body **570**, such as a probe or sonde, to be lowered by wireline or logging cable **574** into the borehole **512**. Typically, the wireline logging tool body **570** is lowered to the bottom of the region of interest and subsequently pulled upward at a substantially constant speed.

During the upward trip, at a series of depths the instruments (e.g., the gamma ray measurement apparatus **100** shown in FIG. **1**) included in the tool body **570** may be used to perform measurements on the subsurface geological formations adjacent the borehole **512** (and the tool body **570**). The measurement data can be communicated to a surface logging facility **592** for storage, processing, and analysis. The logging facility **592** may be provided with electronic equipment for various types of signal processing, which may be implemented by any one or more of the components of the gamma ray measurement apparatus **100**. Similar formation evaluation data may be gathered and analyzed during drilling operations (e.g., during LWD operations, and by extension, sampling while drilling).

In some embodiments, the tool body **570** comprises a gamma ray measurement apparatus **100** for obtaining and analyzing gamma ray field measurements in a subterranean formation through a borehole **512**. The tool is suspended in the wellbore by a wireline cable **574** that connects the tool to a surface control unit (e.g., comprising a workstation **554**, which can also include a display). The tool may be deployed in the borehole **512** on coiled tubing, jointed drill pipe, hard wired drill pipe, or any other suitable deployment technique.

Turning now to FIG. **6**, it can be seen how a system **664** may also form a portion of a drilling rig **602** located at the surface **604** of a well **606**. The drilling rig **602** may provide support for a drill string **608**. The drill string **608** may operate to penetrate the rotary table **510** for drilling the borehole **512** through the subsurface formations **514**. The drill string **608** may include a Kelly **616**, drill pipe **618**, and a bottom hole assembly **620**, perhaps located at the lower portion of the drill pipe **618**.

The bottom hole assembly **620** may include drill collars **622**, a downhole tool **624**, and a drill bit **626**. The drill bit **626** may operate to create the borehole **512** by penetrating the surface **604** and the subsurface formations **614**. The downhole tool **624** may comprise any of a number of different types of tools including MWD tools, LWD tools, and others.

During drilling operations, the drill string **608** (perhaps including the Kelly **616**, the drill pipe **618**, and the bottom hole assembly **620**) may be rotated by the rotary table **510**. Although not shown, in addition to, or alternatively, the bottom hole assembly **620** may also be rotated by a motor (e.g., a mud motor) that is located downhole. The drill collars **622** may be used to add weight to the drill bit **626**. The drill collars **622** may also operate to stiffen the bottom hole assembly **620**, allowing the bottom hole assembly **620** to transfer the added weight to the drill bit **626**, and in turn, to assist the drill bit **626** in penetrating the surface **604** and subsurface formations **614**.

During drilling operations, a mud pump **632** may pump drilling fluid (sometimes known by those of ordinary skill in the art as "drilling mud") from a mud pit **634** through a hose **636** into the drill pipe **618** and down to the drill bit **626**. The drilling fluid can flow out from the drill bit **626** and be returned to the surface **604** through an annular area **640** between the drill pipe **618** and the sides of the borehole **512**. The drilling fluid may then be returned to the mud pit **634**, where such fluid is filtered. In some embodiments, the drilling fluid can be used to cool the drill bit **626**, as well as to provide lubrication for the drill bit **626** during drilling operations. Additionally, the drilling fluid may be used to remove subsurface formation cuttings created by operating the drill bit **626**.

Thus, it may be seen that in some embodiments, the systems **564**, **664** may include a drill collar **622**, a downhole tool **624**, and/or a wireline logging tool body **570** to house one or more gamma ray measurement apparatus **100**, similar to or identical to the gamma ray measurement apparatus **100** described above and illustrated in FIG. **1**, Components of the system **300** in FIG. **3** may also be housed by the tool **624** or the tool body **570**.

Thus, for the purposes of this document, the term "housing" may include any one or more of a drill collar **622**, a downhole tool **624**, or a wireline logging tool body **570** (all having an outer wall, to enclose or attach to magnetometers, sensors, fluid sampling devices, pressure measurement devices, transmitters, receivers, acquisition and processing logic, and data acquisition systems). The tool **624** may comprise a downhole tool, such as an LWD tool or MWD tool. The wireline tool body **570** may comprise a wireline logging tool, including a probe or sonde, for example, coupled to a logging cable **574**. Many embodiments may thus be realized.

For example, a system **564**, **664** may comprise a downhole tool body, such as a wireline logging tool body **570** or a downhole tool **624** (e.g., an LWD or MWD tool body), and one or more gamma ray measurement apparatus **100** attached to the tool body, the gamma ray measurement apparatus **100** to be constructed and operated as described previously.

In some embodiments, the apparatus **100** may be constructed in the form of a downhole tool. Thus, referring to FIGS. **1** and **5-6**, it can be seen that an apparatus **100** may comprise a gamma radiation detector **102** to receive a detector supply voltage, the gamma radiation detector to detect gamma radiation as detected gamma radiation; and a signal processor **104** comprising a pulse height analyzer **116** to determine a relative level of potassium decay energy within a selected band of energy levels with respect to a combination of at least two of potassium, uranium, or thorium, the signal processor **104** comprising a feedback control **106** to adjust at least one of the detector supply voltage or an analyzer gain of the pulse height analyzer to place the potassium decay energy at a selected energy level location when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels. The apparatus **100** may further comprise a downhole tool housing **570**, **624** to attach to the gamma radiation detector **102**.

The apparatus **100** can operate without using a reference radioactive source downhole. Thus, the gamma radiation detector **102**, the pulse height analyzer **116**, and the feedback control **106**, when powered, can operate together to stabilize detection gain of the apparatus **100** downhole without using an on-board radioactive source as a reference gain source.

The downhole tool **570**, **624** may include a memory for using in logging gamma ray measurements made by the detector. Thus, the apparatus **100** may further comprise a memory **306** (see FIG. **3**) coupled to the gamma radiation detector **102**, wherein the memory **306** is used to store a log of the gamma radiation detected by the gamma radiation detector **102**.

Any of the above components, for example the gamma ray measurement apparatus **100** (and each of its elements), the systems **300**, **564**, **664** (and each of their elements) may all be characterized as "modules" herein. Such modules may include hardware circuitry, and/or a processor and/or memory circuits, software program modules and objects, and/or firmware, and combinations thereof, as desired by the architect of the gamma ray measurement apparatus **100** and systems **300**, **564**, **664** and as appropriate for particular implementations of various embodiments. For example, in some embodiments, such modules may be included in an apparatus and/or system operation simulation package, such as a software electrical signal simulation package, a power usage and distribution simulation package, a power/heat dissipation simulation package, a measured radiation simulation package, and/or a combination of software and hardware used to simulate the operation of various potential embodiments.

It should also be understood that the apparatus and systems of various embodiments can be used in applications other than for logging operations, and thus, various embodiments are not to be so limited. The illustrations of gamma ray measurement apparatus **100** and systems **300**, **564**, **664** are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein.

Applications that may include the novel apparatus and systems of various embodiments include electronic circuitry used in high-speed computers, communication and signal processing circuitry, modems, processor modules, embedded processors, data switches, and application-specific modules. Some embodiments include a number of methods.

It should be noted that the methods described herein do not have to be executed in the order described, or in any particular order. Moreover, various activities described with respect to the methods identified herein can be executed in iterative, serial, or parallel fashion. Information, including parameters, commands, operands, and other data, can be sent and received in the form of one or more carrier waves.

Upon reading and comprehending the content of this disclosure, one of ordinary skill in the art will understand the manner in which a software program can be launched from a computer-readable medium in a computer-based system to execute the functions defined in the software program. One of ordinary skill in the art will further understand the various programming languages that may be employed to create one or more software programs designed to implement and perform the methods disclosed herein. For example, the programs may be structured in an object-orientated format using an object-oriented language such as Java or C#. In another example, the programs can be structured in a procedure-orientated format using a procedural language, such as assembly or C. The software components may communicate using any of a number of mechanisms well known to those of ordinary skill in the art, such as application program interfaces or interprocess communication techniques, including remote procedure calls. The teachings of various embodiments are not limited to any particular programming language or environment. Thus, other embodiments may be realized.

In summary, using the apparatus, systems, and methods disclosed herein may provide increased gain stability with respect to gamma ray measurement tools operating in the presence of sensor sensitivity drift, temperature extremes, vibration, or other environmental or design factors relative to conventional mechanisms. These advantages can significantly enhance the value of the services provided by an operation/exploration company, helping to reduce time-related costs.

The accompanying drawings that form a part hereof, show by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the some purpose may be substituted for the specific embodiments shown. Various embodiments use permutations or combinations of embodiments described herein. It is to be understood that the above description is intended to be illustrative, and not restrictive, and that the phraseology or terminology employed herein is for the purpose of description. Combinations of the above embodiments and other embodiments will be apparent to those of ordinary skill in the art upon studying the above description.

What is claimed is:

1. A method, comprising:

detecting gamma radiation as detected gamma radiation;

determining a relative level of potassium decay energy within a selected band of energy levels, with respect to a combination of at least two of potassium, uranium, or thorium; and

adjusting at least one of a detector supply voltage or an analyzer gain to place the potassium decay energy at a selected energy level location when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels.

2. The method of claim **1**, further comprising:

separating the detected gamma radiation according to a preselected number of energy levels.

3. The method of claim **1**, further comprising:

displaying the relative level of potassium decay energy along with the combination of at least two of potassium, uranium, or thorium, in a visible format.

4. The method of claim **1**, wherein the selected band of energy levels include a measured energy level of 1460 keV.

5. The method of claim **1**, wherein the selected band of energy levels has an energy level width sufficient to include an expected amount of energy level measurement drift with respect to the potassium decay energy.

6. The method of claim **1**, further comprising:

repeating the detecting, the determining, and the adjusting on a periodic basis to provide operational stabilization of a gamma radiation detection system.

7. The method of claim **1**, wherein the selected band of energy levels forms a portion of a set of numbered channels that approximately evenly divide a detected energy spectrum into a fixed number of bins.

8. The method of claim **7**, wherein placing the potassium decay energy at a selected energy level location comprises:

moving a measured or simulated peak potassium decay energy location associated with one of the bins to another one of the bins associated with the selected energy level location.

9. The method of claim **1**, further comprising:

measuring actual or simulated energy decay levels of the combination of at least two of potassium, uranium, or thorium, to determine the relative level of potassium decay energy.

10. The method of claim **1**, wherein determining the relative level of potassium decay energy within the selected band of energy levels comprises:

comparing individual potassium decay energy level counts over a predetermined spectrum channel bandwidth to an integrated energy count over the predetermined spectrum channel bandwidth comprising multiple channels that occupy at least the selected band of energy levels.

11. The method of claim **1**, further comprising:

logging the detected gamma radiation as part of a downhole logging operation.

12. An apparatus, comprising:

a gamma radiation detector to receive a detector supply voltage, the gamma radiation detector to detect gamma radiation as detected gamma radiation;

a pulse height analyzer coupled to the gamma radiation detector, the pulse height analyzer to determine a relative level of potassium decay energy within a selected band of energy levels, with respect to a combination of at least two of potassium, uranium, or thorium; and

a feedback control to adjust at least one of the detector supply voltage or an analyzer gain of the pulse height analyzer to place the potassium decay energy at a selected energy level location when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels.

13. The apparatus of claim **12**, further comprising:

a high voltage power supply to supply the detector supply voltage.

14. The apparatus of claim **12**, wherein the analyzer gain is associated with the pulse height analyzer having an energy analysis spectrum comprising a number of channels into which energy is approximately equally divided.

15. The apparatus of claim **12**, wherein the selected band of energy levels correspond to a set of channels on the pulse height analyzer.

16. The apparatus of claim **15**, wherein the selected energy level location corresponds to a single channel on the pulse height analyzer, the single channel included in the set of channels.

17. An apparatus, comprising:

a gamma radiation detector to receive a detector supply voltage, the gamma radiation detector to detect gamma radiation as detected gamma radiation;

a signal processor comprising a pulse height analyzer to determine a relative level of potassium decay energy within a selected band of energy levels with respect to a combination of at least two of potassium, uranium, or thorium, the signal processor comprising a feedback control to adjust at least one of the detector supply voltage or an analyzer gain of the pulse height analyzer to place the potassium decay energy at a selected energy level location when the relative level of potassium decay energy exceeds a predetermined threshold, the threshold based on an energy level of a combination of detected gamma radiation within the selected band of energy levels; and

a housing to attach to the gamma radiation detector.

18. The apparatus of claim **17**, wherein the gamma radiation detector, the pulse height analyzer, and the feedback control, when powered, can operate together to stabilize detection gain of the apparatus downhole without using an on-board radioactive source as a reference gain source.

19. The apparatus of claim **17**, further comprising a memory coupled to the gamma radiation detector, wherein the memory is used to store a log of the gamma radiation detected by the gamma radiation detector.

20. The apparatus of claim **17**, wherein the housing comprises one of a wireline tool housing or a downhole tool housing coupled to a drill string.

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